Vision based Pose domain characterization of an Unmanned Aerial Vehicle using Interval Analysis

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Introduction

To navigate and accomplish their tasks, Unmanned Aerial Vehicles (UAVs) need to locate themselves with respect to the environment and have confidence information about their position. An onboard camera can be used in order to enhance the robot localization using an image-based primary positioning system which enables to overcome GPS and compass unreliability in difficult environments. Solutions to pose estimation from a set of known landmarks ([1]) exist in Computer Vision but they classically provide a punctual estimate of the location. Considering image measurements and landmark positions uncertainties, we aim at characterizing a domain that contains the 3-D pose of a UAV equipped with a camera and proprioceptive sensors. We use an interval-based set-membership approach [2]; which is a powerful tool for rigorous uncertainty propagation([3],[4]).

Problem statement

Estimating the pose of a camera consists in determining the transformation between the world frame $\mathcal{F}_w$ and the camera frame $\mathcal{F}_c$ (Fig. 1).

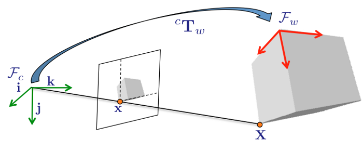

Figure 1: Perspective projection of an object in the image plane

Let $^c\mathbf{T}_w$ be this transformation, defined by: $^c\mathbf{T}_w = \left({}^c\mathbf{R}_w \mid {}^c\mathbf{t}_w \right)$, where $^c\mathbf{R}_w$ and $^c\mathbf{t}_w$ is a function of the attitude and position of the camera in the world frame. To solve this problem, the perspective projection equation of a 3-D point (in the world frame) on the image frame (a 2-D point) is used.

$$\mathbf{x} = \mathbf{K}\,\mathbf{\Pi}\,{}^c\mathbf{T}_w\,{}^w\mathbf{X} \tag{1}$$

with $^w\mathbf{X} = (X, Y, Z, 1)^\top$ the homogeneous 3-D point coordinates; $\mathbf{x} = (u, v, 1)^T$ the pixel coordinates (projection of $^w\mathbf{X}$ in the image); $\mathbf{K}$ the camera intrinsic parameters matrix and $\mathbf{\Pi}$ the perspective projection matrix.

Supposing we have N points $^w\mathbf{X}_i, i = 1..N$ in $\mathcal{F}_w$ and their projections $\mathbf{x}_i$; pose estimation amount in solving the system of equations (1) for $^c\mathbf{T}_w$. This is an inverse problem that is known as the Perspective from N Points problem or PnP. It is classically solved by minimizing the norm of the reprojection error using a non-linear minimization such as a Gauss-Newton of a Levenberg-Marquardt technique.

Interval based Pose Estimation

Placing ourselves in the context of bounded error measurements, each image point $\mathbf{x}_i$ and world point $^w\mathbf{X}_i$ can be represented as an interval vector. Instead of computing the pose by solving equation (1), our approach rely on seeking the domain of all the feasible poses $\mathbf{q}$ such that (1) is verified for $i = 1..N$ according to 2D-3D point correspondences. It consists in computing the solution set :

$$Q = \{\mathbf{q} \mid \exists^w X \in [^w X], K\Pi^c T_w(\mathbf{q})^w X \in [x])\} \tag{2}$$

, which is the set of all feasible pose compatible with $[\mathbf{x}], [{}^w\mathbf{X}]$. The initial domain of the altitude, pitch and roll components of $\mathbf{q}$ is set from onboard sensors measurements. We compute an outer subpaving of Q using Interval Analysis.

Main results

Figure 2: *Left:* UAV in the room. *Right:* Onboard camera view

Experimental trials have been conducted with a quadcopter UAV MK-Quadro from MikroKopter (left image of Fig. 2). This quadcopter is equipped with an onboard camera for image acquisition. Six cubes are used as landmarks of known coordinates and tracked in the image.

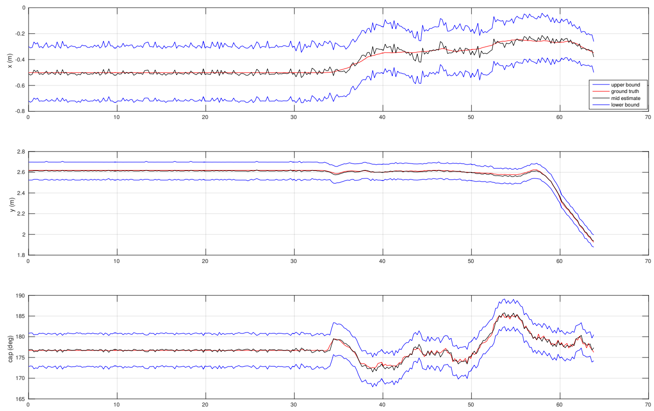

Figure 3: Bounds of the computed pose domain in the whole trial with $\pm 0.5px$ error and $\pm 1cm$ landmark coordinates error. *Black*: mid taken as punctual estimate, *Red*: ground truth and *Blue*: Lower and Upper bounds of the domain

Measurements Uncertainties influence on pose domain size

We can observe the evolution of the pose domain w.r.t. an increasing error bounds in the image measurements in Fig. 4.

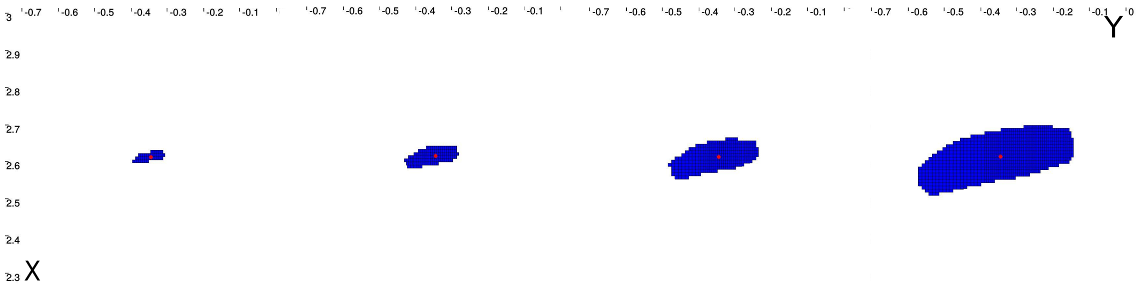

Figure 4: X,Y plane of domain subpaving w.r.t. increasing image tracking error bounds: $\pm 0.25, \pm 0.5, \pm 1, \pm 2$ px

Fault detection and restart

It may happen that no solution can be found with the current set of measurements. In this case, the method outputs an empty set. Possible causes are modeling errors, underestimation of measurement error bounds (it is not generally possible to fix a tight error bound that will cover even rare events), or the presence of spurious measurements. The latter case happens when the landmark tracking algorithm fails. When an empty solution set occurs, a "fault detected" flag is raised, and the landmark tracking is reset.

Conclusion

We proposed an interval based set-membership approach to compute a domain that contains the pose of an UAV, from uncertain bounded-error measurements of known landmarks in the image. While interval methods provide guaranteed results as long as the measurement errors bounds are not violated, setting guaranteed measurement error bound in practice is generally impossible or very pessimistic. Fault detection system is thus implemented, in order to cope with inconsistencies due to tracking errors.

References

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